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No. 774.

TESTS OF FIRE-PROOF FLOORING MATERIAL.—DISCUSSION AND CORRESPONDENCE ON PAPER No. 769.*

By HOWARD CONSTABLE, R. W. LESLEY, CALVIN TOMKINS, OSCAR LOWINSON, GEORGE A. JUST, M. J. BUTLER, J. R. WORCESTER, FR. VON EMPERGER, AND GEORGE HILL.

Mr. Constable.

HOWARD CONSTABLE, M. Am. Soc. C. E.—While the author was working with a center-bearing machine to devise a fair test for the filling between iron beams for high buildings, the speaker was experimenting in the direction of uniformly distributed loads. He found that most of the tests made by the manufacturers were carried out by bricks piled over the surface and well bonded, so as to arch over and either not let their full weight come on the floor, or else produce merely a shearing strain. The speaker tried steel billets, and fairly good results were obtained by carefully piling them parallel with the beams and leaving a space over the center of the floor to allow for deflection, as there is always a settlement while the parts of the arch come to bearing and some deflection as it is loaded up to the point of fracture. The machine now used by him consists of tubes about 15 ft. in height and exactly 1 sq. ft. in cross-section.

* "Tests of Fire-Proof Flooring Material," by George Hill, Assoc. M. Am. Soc. C. E., *Transactions*, Vol. XXXIV, p. 542.

Mr. Constable. Water is run into the tubes, and the pressure due to it is measured by noting the height at which it stands.

The experiments made by the speaker, like those described in the paper, show that the weakest point in tile floors is at the skewback, and that it is important to specify a reinforcing rib coming above and back of the edge of the flange of the skewback beam. When the rib is lower, the arch is destroyed quickly under low total loads.

By separating the area tested in a floor from the adjoining portion by cutting openings across the arch from one skewback beam to the other, the results do not indicate the full strength of the floor.

A floor 13 ft. long and 8 ft. wide which the speaker tested recently was designed for a tenement house where the legal live load is 70 lbs. per square foot. The floor was 4 ins. thick, filled with German Portland cement and screened cinders, and was carried by 4-in. beams running longitudinally 2 ft. apart, and with 3-in. angles in the mid-span 4 ft. 4 ins. apart, riveted vertically to the 4-in. floor beams. This floor had a strength of 350 lbs. per square foot, corresponding to a factor of safety of five. Where vertical angle irons were not used the factor was about two, and where a 2 x 2-ft. section of the concrete was cut off by openings from the remainder of the arch, the factor was reduced to one and one-half. This shows that there is a great difference in the strength of floors, depending upon the extent to which the section is confined longitudinally as well as transversely. In making tests of this nature it is desirable to use loads agreeing with those to be actually carried. In one case the speaker employed a test load of 1 800 lbs. per square foot, which was beyond the strength of the beams supporting the filling and made shoring necessary. Such a floor has a needless factor of safety.

The reason for the use of such an apparently crude method of construction from an engineer's standpoint is to be found in the desire of most people for flat ceilings. The tile flat arch enables a level ceiling to be obtained by simply plastering the underside of the arch.

Large channels in a floor, which may serve as flues under certain conditions in case of fire, promote intense combustion. In a large building recently burned in New York City, two-thirds of the height of the floor beams was entirely naked and on top of the beams there was a flooring of two thicknesses of flooring boards. Consequently there was a large channel or flue between each two beams, and these

channels formed flues which prevented the flooring system from being fire-proof in the present sense of the word. Mr. Constable.

Cement floors and rock-plaster partitions after a fire and after water has been thrown on them are often covered with small pits as if the water had slacked the lime in them. The appearance indicates that the lime may have been burned and then washed away, leaving the sand without a binding material.

R. W. Lesley, Assoc. Am. Soc. C. E.—The experiments described in the paper show that concrete floors are much stronger than those of hollow tile, a conclusion confirmed by many tests made by the speaker in Philadelphia. The Melan arch, in which the concrete is reinforced by iron or steel beams, is merely one particular type of concrete iron construction; the Monier arch, consisting of a net of wire imbedded in concrete, and the Bordenave arch, much used in France in buildings and fortifications, are other types. Possibly the most interesting example of the last type is the 72-in. conduit of the Venice Water-Works, which is made of concrete strengthened with longitudinal rods of I-beam shape, wrapped about with spiral rods. Mr. Lesley.

The Fire Department of New York has raised the point that when concrete has been exposed to fire, and water is then poured on it, it seems to disintegrate into a mass of mud. The floors usually laid in New York in ordinary buildings are made of natural cement, common building sand, and broken limestone. The cement will show more or less carbonic acid gas by reason of the low heat at which it is calcined, the sand probably contains organic matter, and the limestone, if put into a kiln, will become lime, whether the kiln be a 10-story building or a manufacturer's furnace. This naturally suggests that in the construction of a concrete floor intended to resist fire, the materials employed should themselves have been subjected to fire at a high heat. In other words, to a base of Portland cement, formed by combustion and calcination to incipient vitrification, there should be added a silicious sand or gravel, free from organic matter, and broken trap rock, which is formed by fire. In the case of a recent fire in Philadelphia, where the entire ground story of a building was in flames, the cement floor above withstood the fire, although on the same day the tile floors of a building at the corner of Broadway and Bleecker Street, in New York, were destroyed in a fire. At the time of the great fire in Chicago one of a few buildings that remained standing in the burned district

Mr. Lesley. was an artificial stone structure built by the Freer Artificial Stone Company.

Mr. Tomkins. CALVIN TOMKINS, Assoc. Am. Soc. C. E.—The speaker asked if any instances could be cited of buildings in New York City, having limestone concrete floors, where the limestone had been converted into oxide of lime by heat during fires in the buildings.

Regarding the use of crushed limestone in concrete as compared with silica gravel and crushed trap rock, he thought it might reasonably be said, that, so far as any difference exists, it is in favor of limestone, since this is cheaper than the other materials, and for the additional reason that the effect of extreme heat on limestone is to convert the carbonate of lime into the oxide of lime, and in this process heat is used up. This chemical change begins on the outside of the particles of stone and proceeds very slowly toward the interior; it is only at a very high temperature that any chemical change is effected at all. The fire-proof qualities of plaster of paris green are accounted for in a similar way, the water of crystallization being driven off by heat which is used up in the process of performing chemical work. A limestone aggregate in concrete for arch construction and for other purposes has always been, and is now, the principal aggregate used in New York City, and unless some decided failures due to its use can be proved, it seemed unfortunate to interfere on theoretical grounds with established custom, and thereby entail needless expense on building operations.

Mr. Lowinson. OSCAR LOWINSON, Jun. Am. Soc. C. E.—In respect to manufacturing buildings, there is a question as to the power of a floor-arch to withstand impact, such as the falling of a case weighing from 600 to 1 200 lbs. from a height of several feet. The speaker had never succeeded in finding sufficient records of floor arches failing under impacts to determine beforehand the strength in the arch, and the information on the subject is meager and vague. Probably the reason for the lack of failures of this sort is shown by the large static loads which tests like those described in the paper show that the arches sustain. The speaker believed that in manufacturing buildings and warehouses, the arch should be regarded principally as fire-proofing, secondary reliance only being placed on its strength. His practice was to halve to the beams the sleepers carrying the floor, as this construction does not take up more floor space. The only objection to such construction

is the formation of air spaces, which is of secondary importance in this instance, because the floor itself would burn in case of fire. At the same time the surest test of strength in an arch will always be its power to withstand the strains coming on it, and he believed that tests should be made with that end in view. Mr. Lowinson.

GEORGE A. JUST, M. Am. Soc. C. E.—The tests made by the author emphasize what earlier tests in this direction have shown, viz., that the weakness of the hollow tile side-construction arch exists in the skewbacks and in the horizontal webs of the blocks adjoining the skews, and that the end-construction arch when properly laid is much stronger than the side-construction arch. Mr. Just.

The adoption of any system of floor arching generally depends on such practical considerations as the necessity for flat ceilings, facility in construction, cost or fire-proof qualities. The object is to get the cheapest arch that will do the work. Patentees and manufacturers like to demonstrate the superior strength of their own arches, but as in all other structural work, it is only necessary that the arch does its work with safety.

It would seem from the present and some older tests, that floor arches, whether old-style common brick, concrete, Melan, metropolitan or end-construction hollow tile, meeting the requirements generally found in buildings, can be laid to sustain an ultimate load of 2 000 lbs. per square foot of arch. The old hollow tile side construction, however, even under the most favorable conditions, seems hardly to reach half this strength.

The live loads fixed by the present New York Building Law only range from 70 lbs. in dwellings to "150 lbs. and upwards" for factories and warehouses. Hence any of these systems can be used with safety in ordinary building operations, and the selection of any one will be from considerations other than strength. The prices too, under severe competition, have become very much alike for the different systems.

In his experience, the speaker had never observed a failure in floor arches that could be charged to the system used. Failures could generally be traced to careless laying, such as applying the mortar only to the edge of the blocks; to the weakness of the channel irons usually placed along the walls, which, when with little superincumbent weight, are sheared off and moved horizontally; or to an insufficiency of tie-

Mr. Just. rods; to placing the tie rods too high on the web; or to the bending or removal of the rods by the mason, who often looks upon them as more ornamental than useful, and as interfering with the easy execution of his part of the work. Of course in special cases, high ultimate strength becomes an important consideration. In his practice he had met cases in breweries where the live and dead loads amounted to almost 1 000 lbs. per square foot of floor. In such cases the old common brick row-lock arch would be found stronger and as economical as any of the more modern systems.

CORRESPONDENCE.

Mr. Butler. M. J. BUTLER, M. Am. Soc. C. E.—The author has not dealt with the question of the relative fire-resisting qualities of different materials. Terra cotta has had a most extensive and searching series of tests, some voluntary, others involuntary. Of the former, the best are those recorded in the *American Architect* for March 28th, 1891, and of the latter, probably the most severe ever given any material, the great fire in the Athletic Club Building in Chicago, in 1894. All the floors in the building were of porous terra cotta, and the entire structure, where protected, was unharmed.

Some recent tests made under the observation of the writer show that concrete will not stand the harsh conditions incidental to fire. If the cement has not dried out thoroughly, on exposure to a high temperature it will crack and crumble into pieces, or if thoroughly dried out and then subjected to a high temperature it will crack and crumble to pieces if drenched with water while hot. If this be the rule, what avail is it that the floors be strong; they will go down just as easily as though of wood. More light is required on this point, and extensive and authoritative experiments are needed before concrete can be considered a fire-proof material.

Mr. Worcester. J. R. WORCESTER, M. Am. Soc. C. E.—While the paper does not give all the data which might be desired, it certainly sheds considerable light on the subject, and it is a question whether a few conclusions in addition to those of the author cannot be drawn from the results. The great lack of positive information by which to determine the proper style and thickness of flooring to be used in certain cases must have troubled many engineers, and it may be useful to work out

whatever reliable tests there are to such form that they can be easily used, although any results must of course be considered as only preliminary, and subject to alteration and improvement, as may be found necessary upon later information. Mr. Worcester.

With this object in view the writer has extended and rearranged certain tests given in the author's Table No. 3. Nothing has been done with the Melan arches, as Table No. 1 is in such form that it can be readily used, and, moreover, the combined steel and concrete is susceptible of such an infinite variety of modifications that any general classification would be impossible from the data at hand. With the terra cotta and clay arches, however, there are comparatively few types to deal with.

The arches built without mortar have not been included for two reasons; first, because the tests show great irregularity in the results, and second, because in practice it is almost always the case that mortar of some kind is used. In order to bring the results to the same basis for comparison, the ultimate load has been reduced to the equivalent load per square foot uniformly distributed on a 60-in. span, assuming that the rupture was caused by the bending moment, which, of course, was not always the case in the side-construction arches. In this reduction, in a few cases, it is not possible to tell from the paper precisely the length of arch over which the load was distributed, but it is believed that the errors are not large on this account.

TABLE OF EQUIVALENT UNIFORM BREAKING LOADS.

No. of Test.	Nominal depth.	Rise of arch.	Pounds Per Square Foot.			Remarks.
			Porous terra cotta. End construction.	Hard material. End construction.	Hard Material. Side construction.	
91	6 ins.	3.5 ins.	.....	820	.....	
95	8	5	.....	1 360	.....	
96	8	5	1 520	.....	.....	
94	8	5	.....	.....	500	Ultimate strength too low, but did not crack at a low figure.
93	8	6	.....	.....	1 200	
100	8	7	1 630	.....	.....	
101	8	7	.....	1 780	.....	
92	9	6	.....	2 980	.....	Phenomenally high.
97	10	7.5	.....	.....	1 180	
98	10	8	.....	.....	1 240	
99	12	10	.....	.....	1 710	Classed with side construction because skewbacks were so made.

Mr. Worcester. From this arrangement of the table two points of interest are apparent; first, the porous terra cotta end-construction is of about the same strength as the hard material of similar form; second, the ultimate strength is approximately in proportion to the effective depth or rise of arch. Assuming this latter conclusion to be true, it is possible to arrive at a simple rule for proportioning the arches, for the load per square foot must be inversely proportional to the square of the span and directly proportional to the depth, or, expressed algebraically, $w = c\,d \div l^2$ where c is a constant to be determined experimentally.

To get at the proper factor of safety, it is interesting to observe that in Test No. 101 a slight crack was observed when the load had only reached 14% of the ultimate capacity. In many of the end-construction arches it is observed that the first crack is noticed very early, though the ultimate strength is great. In order to avoid cracks it is perhaps proper, therefore, to take for a working load not over one-eighth the least of the crushing loads for end construction, which would give a value of c in the above formula of 720, supposing d to be in inches and l in feet.

The following table, based upon this formula of $w = 720\,d \div l^2$, may be taken as giving safe loads per square foot for arches similar to those represented by the author's tests, though possibly the figures approach those at which slight cracks may be expected. So far as shearing strength is concerned, while the factor of safety may not be great in this respect for the short spans, in no case would the table allow a shear per square foot as great as the least under which any arch tested failed by shearing.

TABLE OF LIMITING LOADS PER SQUARE FOOT FOR TERRA COTTA AND CLAY ARCHES.

Nominal depth.	Effective depth.	Span of Arch or Distance Between Beams.					
		3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.
6 ins.	3.5 ins.	280 lbs.	154 lbs.	100 lbs.			
8	6	480	270	173	120 lbs.		
10	7.5	600	337	216	150	110 lbs.	
12	9	720	405	260	180	136	100 lbs.

FR. VON EMPERGER, Esq.—The tests of hollow tile floor arches without mortar joints are particularly valuable because they enable engineers who do not care to rely on the strength of mortar in such joints to ascertain what loads an arch will carry if the joints are badly made or the centers struck too early. The writer believes, however, that the results of some of the tests are open to question, this impression being received while witnessing Test No. 92, in which the load was distributed over nearly the whole span by planks. In such a case the center of the arch bends and relieves itself almost entirely, while the load is applied chiefly near the skewbacks. This can be seen in Plate X*, Figs. 2, 3 and 8, and still better in Fig. 8, page 557,* where cracks appear only in the skewbacks, in consequence of the load coming upon them alone. A comparison of Tests Nos. 92 and 95 gives rather conclusive evidence on this matter. Arch No. 92, having a span of 65 ins., had frozen mortar and was but 24 hours old when tested, yet it did not break at 2 545 lbs. per square foot. Arch No. 95, having a span of 60 ins., and built of the same style of blocks, with a covering of mortar over the top, was three months old when tested, yet it failed under a load of 1 534 lbs. per square foot (Table No. 3 gives 767 lbs.). The only apparent reason for such a difference is that the first arch was loaded over 95% of its area, and the weight was transmitted by the manner of loading to the I beams, while only 5% of the area of the second arch was loaded. The writer therefore believes that in studying the paper, attention should not be paid to such tests as were made with distributed loads. The results of the tests with center loads are given in the table on page 134, the only change made in the author's figures being to double the center loads mentioned in the paper, because an error is made in comparing distributed and center loads when the latter are not doubled. Mr. von Emperger.

The writer believes the last form given in the table to be the best, but, considering the forms now in the market, the end construction is to be preferred, mainly because the tests of this form with and without mortar joints showed considerable similarity in strength, while this was not the case with the side-construction blocks. The maximum live loads these floors are adapted to carry may be determined by the following rule devised by the writer: The sum of the maximum live load proposed and one-third of the dead load must not exceed one-eighth

* See *Transactions*, Vol. XXXIV.

Mr. von Emperger.

of the average strength as determined by at least three tests. None of these tests, however, should show a strength less than three-fourths of the average, or six times the sum of the live load and one-third the dead load. Under this rule end-construction tile arches with 8-in. blocks and 60-in. spans have a permissible live load of nearly 200 lbs. per square foot. The calculations on page 528 of Volume XXXIV of the *Transactions* must be corrected accordingly.

All Melan and concrete arches described in the first part of the paper were tested with center loads, and the writer believes that the loads per square foot given in the table in the paper should be doubled. The most apparent difference between the failure of Melan arches on

BREAKING LOADS OF HOLLOW TILE ARCHES.

Test number.	Construction.	Rise. Inches.	Span. Inches.	Breaking load. Pounds per square foot.	Joints.
1*.....	Side.	9	72	856	With mortar.
93.....	"	6	60	1 336	"
94.....	"	5	60	762	"
109.....	"	5.5	60	600	Without mortar.
110.....	"	5.5	60	1 000	"
112.....	"	5.5	60	500	"
113.....	"	5.5	60	550	"
95.....	End.	5	60	1 534	With mortar.
96.....	"	5	60	1 714	"
100.....	"	7	60	1 838	"
101.....	"	7	60	1 994	"
102.....	"	8.75	60	1 478	"
103.....	"	9	60	2 380	"
107.....	"	9.5	60	1 202	"
108.....	"	9.25	60	1 446	"
2*.....	Side.	9	72	1 616	"

* See *Transactions*, Vol. XXXIV, p. 528.

the one hand and concrete and tile arches on the other hand is that the concrete of the former simply cracked, while the latter dropped to the ground. In the latter case the tie rods were entirely uninjured, while in the Melan arch tests they failed. Arch No. 81 failed through the rupture of a tie rod, as did Arch Nos. 82–83, although this fact is not recorded. In Arch No. 84 the tie rod was slack, and the writer desired to have the test omitted altogether as valueless. The tests of Arches Nos. 81 and 83 gave breaking loads of 3 334 and 6 520 lbs. per square foot (the table in the paper gives half these loads) and are very satisfactory, but do not give full justice to the arches.

In testing floor arches the load a which they are built to carry corresponds with a horizontal thrust h. The breaking load A or

$8a$ produces a horizontal thrust $8h$. The tie rods usually made have a factor of safety of 4, so that their elastic limit is reached when the horizontal thrust becomes $2h$. If the load $8a$ is to be used in testing arches and the elastic limit of the metal in the ties is not to be exceeded, four ties must be provided for tests in which one only is commonly used. The tests of tile and plain concrete arches showed the reliability of the material employed because the tie rods remained intact, while on the other hand the rods employed in the Melan arch tests were entirely inadequate. In using flat iron ties bent around the lower flanges of the spandrel beams, the writer intended to make a connection where there would be no means of screwing the arch tight after it was built, and thus increasing its strength. The rods were of poor material and presumably bent cold, as they opened like the fingers of a hand; they were applied too low to give proper resistance to the thrust, and they were not tight enough from the start; in fact only tie rods with nuts and screws should be used. For these reasons the writer believes that the results of Tests No. 81 and 83 do not correspond with the breaking loads of the arches, although they may be very near them. The cracks which appeared were simply a consequence of the increase in the span caused by the stretching of the ties. Mr. von Emperger.

Arch No. 87, which had been loaded in Tests Nos. 78, 79 and 80, is the only one where neither arch nor tie rods were injured; it carried 3 890 lbs. per square foot. This amount is double that given in the paper, but as a matter of fact it is not large enough, as the load was applied eccentrically. The writer does not believe that this eccentricity will amount to much in the case of small spans.

A comparison of Test No. 77, made on a bent iron beam which failed under 14 000 lbs., and a plain concrete arch which failed completely under 31 250 lbs., leaving the tie rods uninjured, with Test No. 83, made on an arch which carried 58 750 lbs. until the tie rod failed, shows very well the use of the combination of iron and concrete. The condition of the concrete of Test No. 83, after the load was withdrawn, is described in the paper, and indicates that it is incorrect to speak of a failure in this concrete, in the full sense of the word. The iron ribs were taken out with a sledge and found to be without any permanent deflection.

The writer desires to draw attention to the eight-day test of Melan

Mr. von Emperger.

arches, as the fact that they would carry any load at all after such a short time has been doubted. Such tests have not been made before, and are of importance as indicating the length of time centers must be left in place, and whether the arches can be loaded immediately after the centers are struck. They show that the arches are sufficiently safe after eight days to allow walking on them, and Test No. 80 indicates that they will carry any load that may come upon them during subsequent building operations. Taking the results of the tests and submitting them to the writer's rule given on page 133, it will be seen that the permissible live load for the light Melan arches is 500 lbs. per square foot, and that for the heavy type is over 1 000 lbs.

Mr. Hill.

GEORGE HILL, Assoc. M. Am. Soc. C. E.—In closing the discussion, the author submits in the table on page 139 the results of an additional series of tests made recently at the Ireland Building, in New York City, of commercially constructed fire-proof arches under various methods of loading. The arches were in all cases 8-in. side-construction, hard tile protection skews of 50-in. span. Tests were made with concentrated loads applied centrally and eccentrically, and with distributed loads on entire bays and on sections cut from the bays. The distributed loads were applied by means of cribwork, consisting of 3 x 4-in. yellow pine sticks 1 in. apart in the clear, decreasing in length and giving a true condition of uniform loading, as was demonstrated by series of levels taken throughout an entire test, showing that the arch curved uniformly over its span. These tests show the marked influence of length on strength, the inappreciable influence of the tie rod as a separating member, its small value in intermediate spans where the skewback beams are framed at both ends, and the great value of filling as a means of distributing the load. They also serve to indicate how great must be the capacity of a testing machine to give its results positive value.

The machine described by Mr. Constable is one which the author thought of early when considering the question of design, and discarded for the following reasons: First, because of its very limited capacity; second, because in an arch of great flexibility or elasticity there would be danger of the tubes touching at the top, concentrating their weight on lines of the base instead of over their entire area; third, because they are liable to freeze in cold weather; fourth, be-

cause in failure there is the likelihood that the tubes will pass down into the ground, may be ruptured, may rupture their connections, starting the water everywhere, and must be lifted out; fourth, because the weight is transmitted beyond the skewback beams to their connections, thus straining the entire framing around them to an unknown amount. Mr. Hill.

The author considers the practice announced by Mr. Lowinson of disregarding the strength of the fire-proof arches is very far from being good engineering, since it is only necessary to employ a carefully designed form of floor arch, to have adequate strength without any additional expense, and to save the cost of the wooden construction.

The correspondence by Mr. Worcester and Mr. Von Emperger emphasizes the remark in the paper that the tests do not afford sufficient data from which to draw conclusions, since in one case the arches laid without mortar are specially referred to, while in the other case they are expressly thrown out. Disregarding the derivation, the table of limiting loads per square foot given by Mr. Worcester is reasonably correct. Its value, however, except under unusual conditions, is minimized by the fact that other considerations make it desirable to employ an arch that is as deep as the beam which serves as its skewback. The cracking mentioned is due to inequality of bearing, and does not affect the strength seriously.

Taking up Mr. Von Emperger's communication, the author would say that throughout the whole of test No. 92 the center of the arch received its full loading, and was in no case relieved. Referring to Plate X,* Figs. 2, 3 and 8, it will be observed that in Fig. 3 the blocking is bent. In Figs. 2 and 8 the arch had failed, but in both cases, immediately prior to failure, the load was uniformly distributed over the entire area of the arch. Referring to Fig. 8 of this plate, it will be evident from the horizontal direction of the cracks that the arch failed along true thrust lines, as was shown clearly in the blocks. Mr. Von Emperger did not see these tests, and so the error is explicable.

Referring to Test No. 92, the arch was loaded until the extension of the tie rods by horizontal thrust opened the bottom joint as described, and caused a spall the size of a thumb nail at the top. Had the conditions been as stated by Mr. Von Emperger, this could not have occurred. The reason for the great strength was that the freezing of the mortar

Transactions, Vol. xxxiv, p. 565.

Mr. Hill. gave an absolutely homogeneous joint of great compressive strength, which developed to the fullest extent the strength of the blocks. Test No. 55 failed, not because of the concentrated load, but because of the porous terra cotta skewbacks, the failure in which began at 43% of the maximum load. The statement made concerning the character of the tie rods used in the Melan system tests is an error, as the broken pieces which the author has in his possession show a break square across below the bend. By reason of these inaccuracies, the author considers it unnecessary to discuss this correspondence further.

Comparing Table No. 3* with the table on the opposite page, a very wide difference between test and actual conditions will be noticed immediately, and the author therefore feels that he has accomplished the purpose for which the tests up to No. 114 were inaugurated when he emphasizes the three conclusions drawn at the close of the paper.

Coming to the commercial consideration of the arches, it is necessary to remember that wood in the floors is being gradually eliminated, and that within a short time it is probable that the universal practice will be to lay concrete immediately over the floor arches, covering them or not according to the uses to which the rooms are to be put. When this is done, the concrete being more expensive than the blocks, an arch block will be used, so as to fill the void to the top of the beam flange. All kinds of material are used in the arches for jointing, good, bad and indifferent mortar, frozen mortar or mud; and if it is practicable to fulfil all of the conditions required of the floor arches without additional expense, and secure in addition sufficient strength to be independent of the character of the mortar, engineers will be relieved of considerable anxiety. Voids between the top and bottom surface of the floor are undesirable if continuous, as they serve no useful purpose.

Taking up now the tests under practical conditions, it is safe to draw the following conclusions:

First.—The ordinary practice of shallow arches and cinder filling, using the side-construction protection skew, leaves an insufficient margin of strength for any purpose except that of office buildings.

Second.—The architect in specifying for the strength of floor arches should state all of the conditions under which the tests will be made,

Transactions, Vol. xxxiv, p. 567.

TESTS OF HARD TILE SIDE-CONSTRUCTION PROTECTION SKEW ARCHES, WITH ABOUT 4 INS. OF CINDER FILLING.

The span was 50 ins.; the rise, 5 ins.; the depth of skew, 8 ins., and the area of the tie rods 0.5 sq. in. in every case.

Test number.	Width, inches.	Arch area. Square feet.		Total load. Pounds.	Load per square foot.		Horizontal thrust. Pounds.	Shear per foot skew.	Load.	Deflection. Feet.	Remarks.
		Total.	Loaded.		Arch.	Loaded area.					
114....	264	90	0.73	9 750	.....	13 350	12 150	.....	Center.	.....	Whole length of section cracked } one bay.
115....	264	90	0.73	18 500	.....	25 360	23 150	.....	"	.....	Sheared near center of bay }
116....	264	90	0.73	11 900	.....	16 300	14 890	.....	"	0.039	Loaded block crushed.
117....	264	90	0.73	10 000	.....	13 700	12 500	.....	"	0.025	East end }
118....	264	90	0.73	13 500	.....	18 500	16 880	.....	"	0.083	West end } one bay.
119....	264	90	0.73	14 500	.....	19 860	18 130	.....	"	0.12	Center }
120....	54	18.72	0.73	9 000	481	12 330	11 250	1 000	"	0.08	Cut section.
121....	48	16.64	0.73	10 000	602	13 700	12 500	1 250	"	0.036	"
122....	48	16.64	0.73	6 000	361	8 225	7 500	750	"	0.078	"
123....	264	90	10.55	20 000	.....	1 895	50 000	.....	Distributed.	0.034	"
124....	264	90	10.55	25 000	.....	2 366	62 500	.....	"	0.051	Section affected 6 ft. long.
125....	54	18.72	9.7	11 500	614	1 180	28 750	1 280	"	0.115	Open bays; side skews sheared.
126....	48	16.64	10.28	17 000	1 020	1 655	42 500	2 126	"	0.068	Cut section; center depressed.
127....	48	16.64	10.28	12 500	752	1 215	31 250	1 565	"	0.038	" "
128....	48	16.64	10 28	15 500	933	1 510	38 750	1 940	"	0.065	Skew failed.
129....	264	90	10.28	22 500	.....	2 190	56 210	.....	"	0.16	Skew sheared next open bay.
130....	264	90	10	15 000	.....	1 500	37 500	.....	"	0.018	
131....	264	90	0.73	8 000	.....	10 900	10 000	.....	Center.	0.026	Cinders removed.
132....	264	90	9.75	17 500	.....	1 800	43 800	.....	Distributed.	.....	" "
133....	48	16.64	10.28	9 500	570	925	23 775	1 188	"	0.08	" " Sheared at skews.
134....	48	16.64	0.73	4 100	246	5 620	5 130	513	Center.	0.33	" " Broke underneath.

NOTE.—The arches tested were similar to those shown in *Transactions*, Vol. XXXIV, p. 559, Fig. 11.

Mr. Hill.

Mr. Hill. since the strength of an arch 5 ft. long is totally different from the strength of an arch built of the same blocks 15 ft. long, the strength of the arch when covered different from the strength of the arch without, and the strength of the concrete cover different from the strength of the cinder cover. The strength per square foot when loaded with a concentrated load is different from the strength per square foot with a uniformly distributed load, and the effect of a uniformly distributed load different under different conditions of distribution, the most satisfactory result being obtained where an elastic material like wood is employed under proper conditions to effect the distribution.

Third.—As a general lesson to be drawn from all of the tests, no test can be of full value that is not carried to the destruction of the arch.